Comparison of O_2-N_2 and H_2 Plasma Cleaning for EUV Applications

E. Kosmowska, R. Vane, and C. Moore
XEI Scientific, Redwood City, CA 94063

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Outline

- Fundamentals of plasma cleaning

  …with air …with hydrogen
- Measurement of hydrocarbon removal
- Understanding Cleaning Rate
  - Simple model (flow, pressure, distance)
- Comparison of N_2-O_2 vs. H_2
- System design
- Conclusions

Plasma cleaning with N_2-O_2

Applications

- Vacuum systems/components with hydrocarbon contamination
- Cleaning of new chambers or after maintenance
- Prior to deposition of interface-sensitive films

Advantages

- Removes hydrocarbons by chemical reaction with reactive oxygen species resulting in volatile products
- Feedstock gas free (air) or inexpensive (CDA)

Disadvantages

- Not compatible with systems containing Ag or Ru
- May oxidize some surfaces if at elevated temperature
- Less efficient at removing double–bonded carbon compounds

Plasma cleaning with Hydrogen

Applications

- Cleaning materials that are incompatible with oxygen-based cleaning
- Reduction of metal oxide films

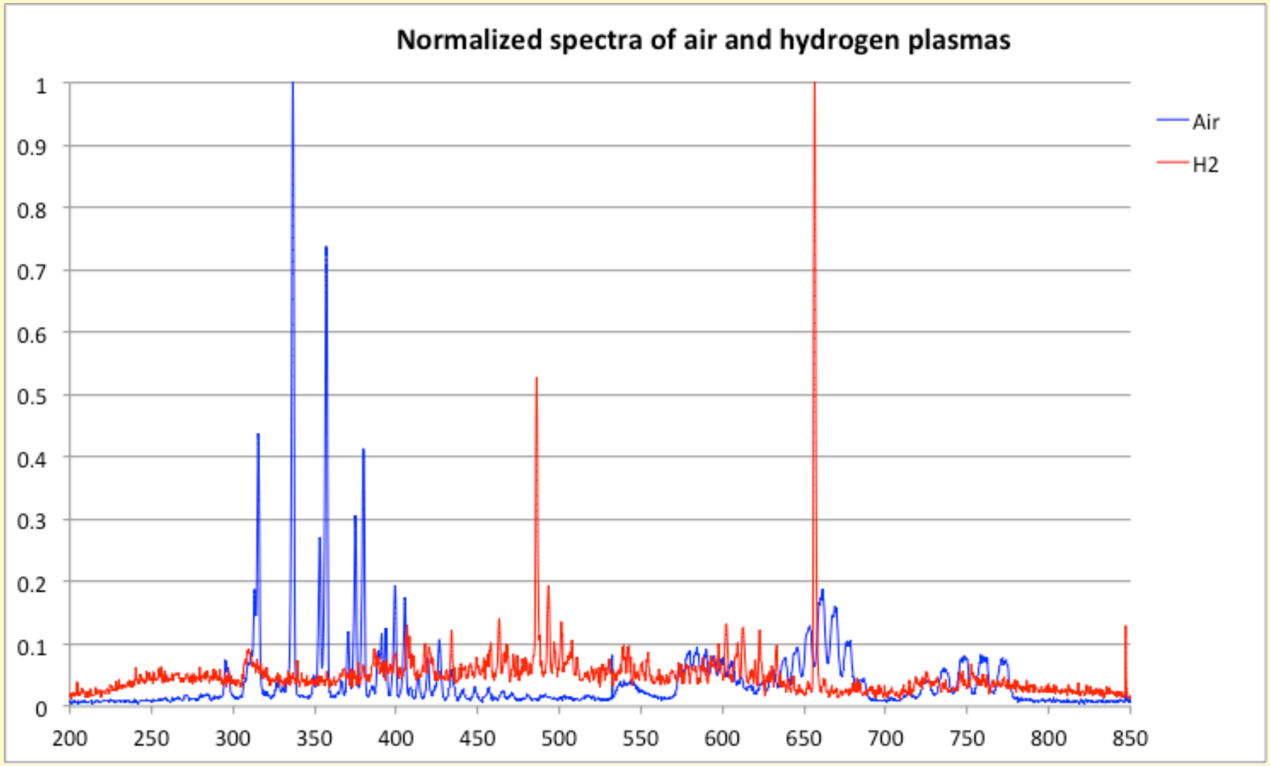
Advantages

- As with air, innocuous by-products
- Increased gas mean-free-path (2x nitrogen)

Disadvantages

- Gas manifold more complex (need to vent and purge)
- Material requirements along gas path
- Safety infrastructure/risks (point-of-use generator)

Hydrogen and Air spectra



- Relative plasma strength tracks intensity of optical emission from plasma
- Optical emssion from H2 in visible band is weak, plasmas appear to eye as dim

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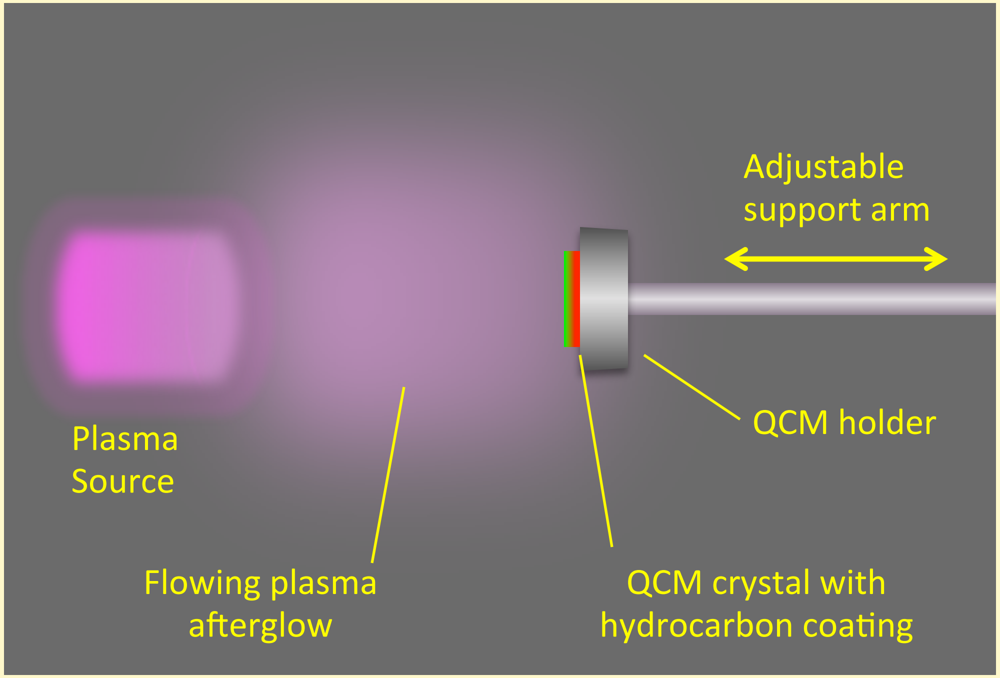
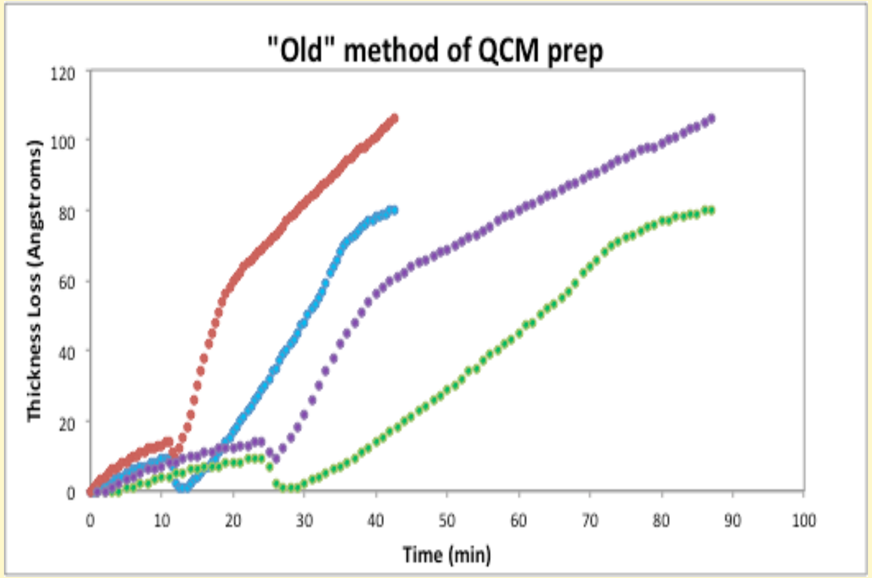
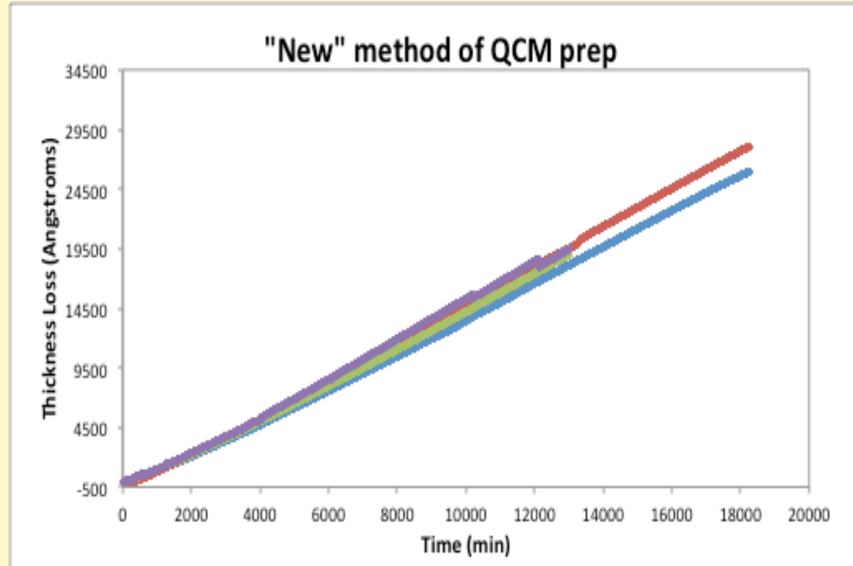
Quantifying Hydrocarbon Cleaning



- Use established quartz crystal microbalance (QCM) tools
- Deposit hydrocarbon-based (HC) solid film on QCMs
- Remove HC layer using Evactron™ plasma cleaner
- Record Δ(thickness) versus time to calculate cleaning rate

Hydrocarbon (HC) layer: preparation method matters





Slope of line is proportional to cleaning rate

Old method (FGM):

- Layers limited to 100-500 Å
- Slope (cleaning rate) not linear with time (variations in the properties of HC layers)
- Cleaning rates varied under "identical" preparation conditions

New method (CMR):

- High linearity over entire thickness
- Increase in film thickness (several microns)
- Results repeatable and consistent
- Parametric studies w/o breaking vacuum

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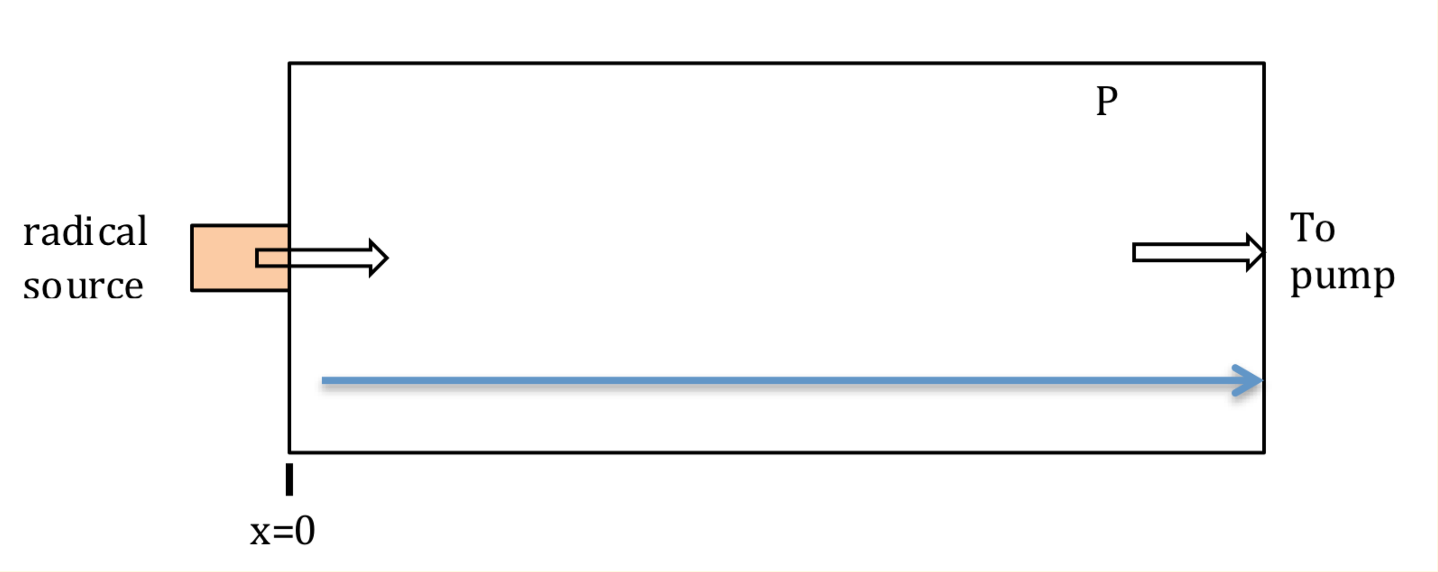
Pressure Effects: A Simple Model



#radicals at distance *x* = F * (source flux) * exp(-x/R)

where "F" is flow factor ≈ f / (f + constant)

"R" is the loss-based "reaching distance"

But R ≈ (gas constant k)/P

and source flux ≈ (constant ϒ)*P

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Simple model (continued)

- Combining: normalized #radicals = F * P * exp(-x * P/k)
- Pressure too low ➔ reduced production of cleaning species
- Pressure too high ➔ reduced reach due to losses/scattering

★- 1) at a given distance from plasma there is an optimal pressure for maximum cleaning rate
2) larger distances require lower pressures

(Note: Effect of gas flow rate assumed constant for a given chamber and pump stack)

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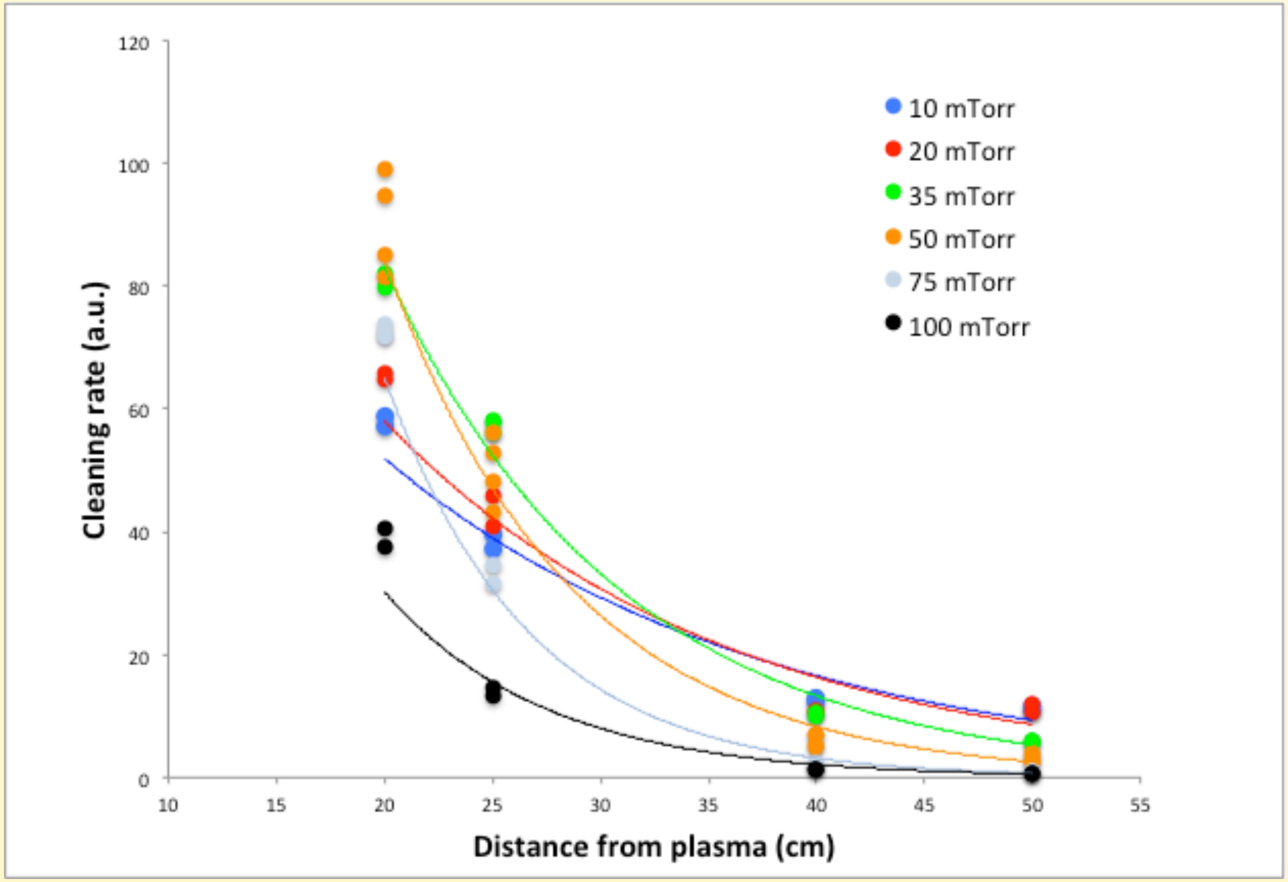
Removal rates (air) vs. distance @ 20W



- Cleaning rate falls off exponentially away from source all pressures
- Highest rate occurs not at highest or lowest pressure

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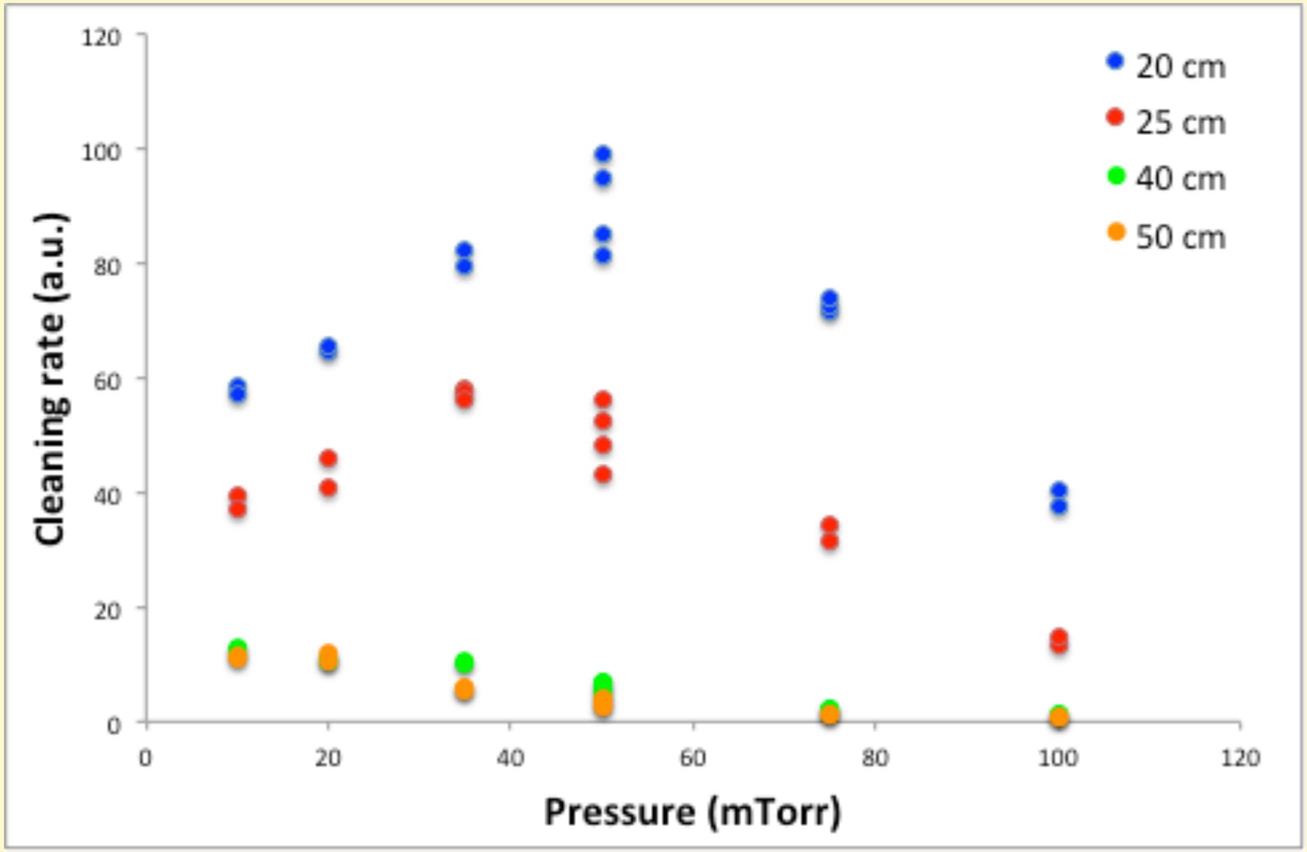
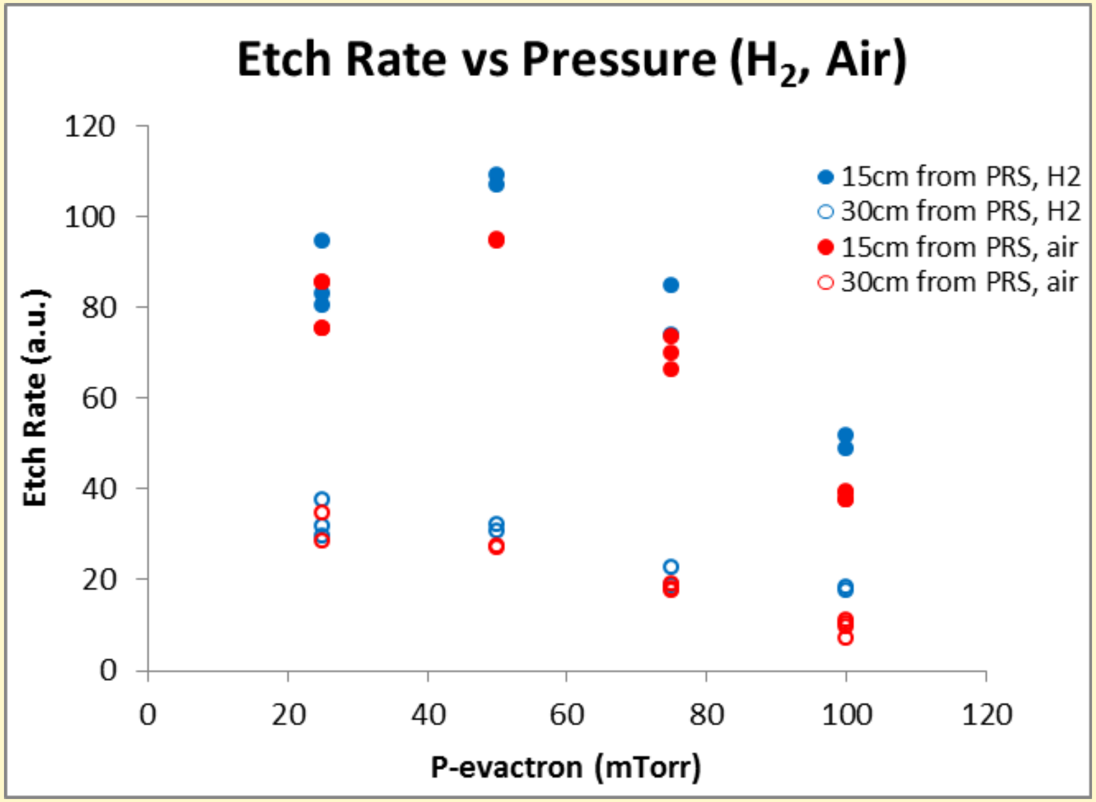
Removal rates (air) vs. pressure @ 20W



- Optimal pressure depends on distance from plasma source

Removal Rates in Air versus Hydrogen



At 20 W plasma power, Hydrogen plasma removes hydrocarbons (HC) slightly faster than oxygen plasma under the same conditions

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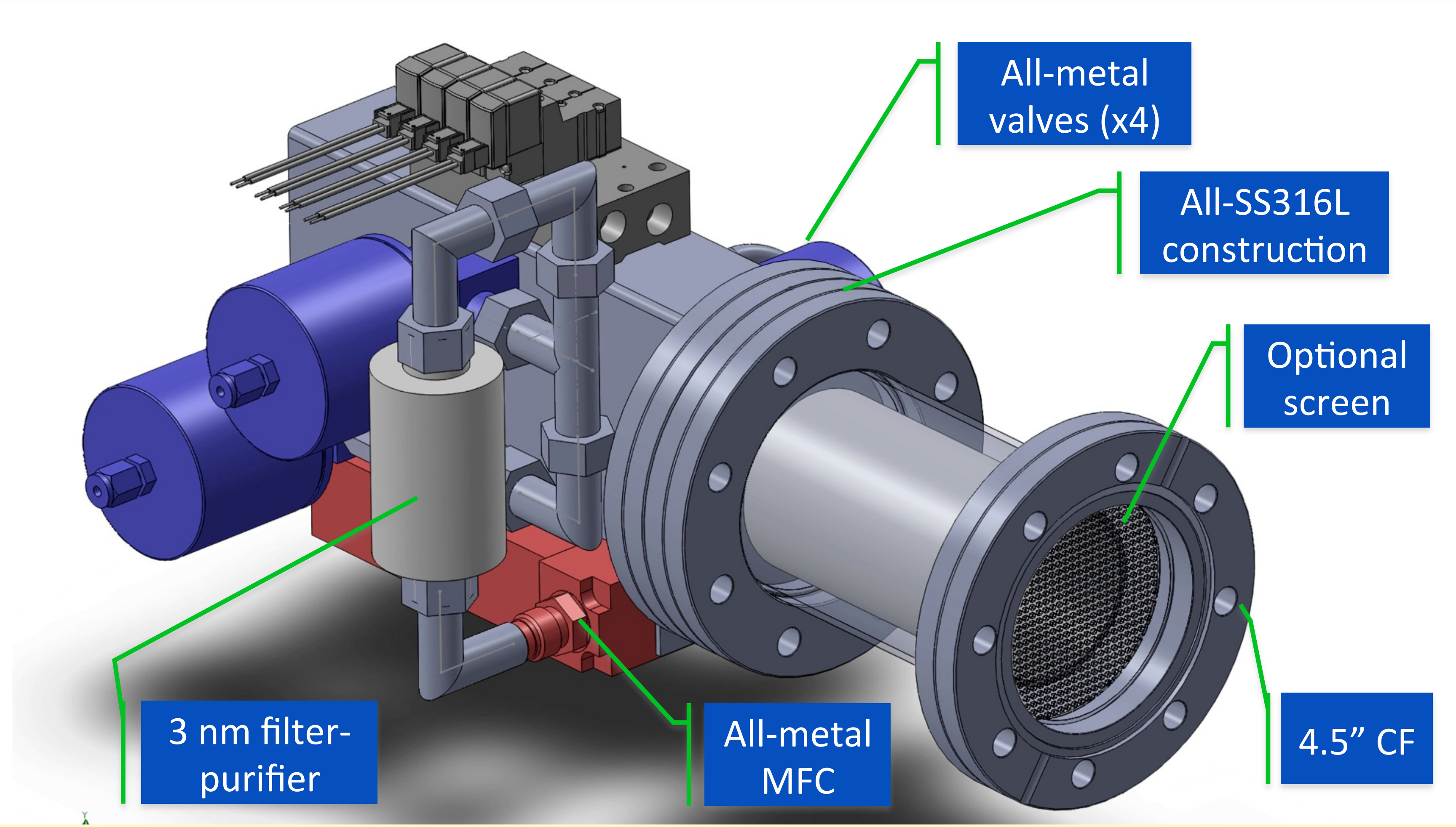
Prototype H_2 Plasma Cleaning System



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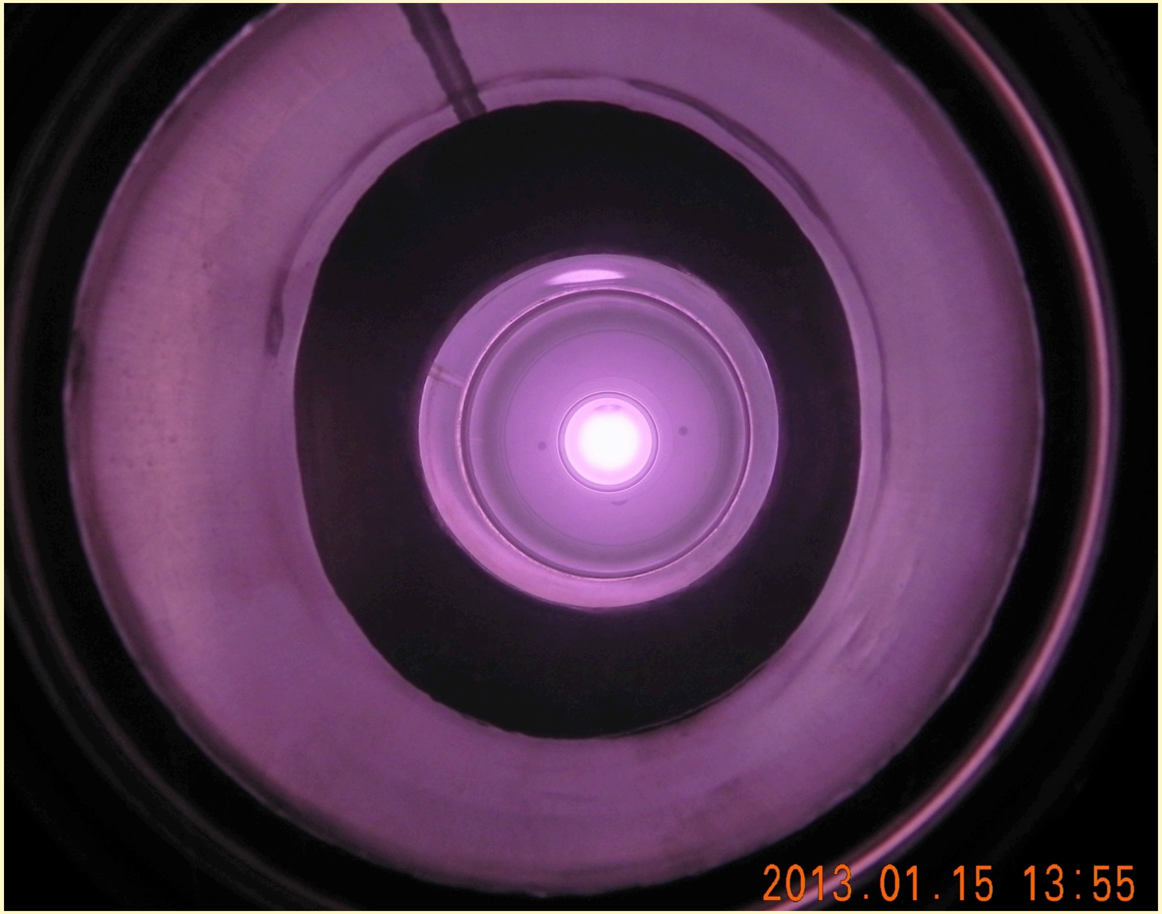
50 W plasma operating in H2



-New electrode design as seen through 6” CF cross

Conclusions

- New electrode design capable of 50 W plasma power (> 150 W in limited tests)
- For both air (O_2-N_2) and hydrogen (H_2) it was found that gas pressure selection is a key for maximizing cleaning rates
- Higher pressures increase scattering by the gas
- Lower pressures required to reach farther

  -Reduced pressure small effect on reactant concentration (since $N_{gas} \gg n_{electron}$)
- A stable method for hydrocarbon film preparation allows for parametric studies of plasma cleaning

Prototype Technical Specs

- SS316L construction: no elastomers
- H_2 wets only metallic surfaces
- No/minimal ceramic materials
- Charge trapping screen option
- Low-particle and ultra-clean construction (SS 316L)
- Elastomer-free gas manifold: all-metal seal valves
- In-line 3 nm filter/purifier
- Clean room assembly and packaging